AOARD REPORT

TITANIUM ALLOYS AND TITANIUM ALUMINIDES FOR AUTOMOTIVE APPLICATIONS JAPAN, DECEMBER 1 THROUGH 13, 1993

Dec 1-13, 1993
Daniel Eylon
University of Dayton

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AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

ASIAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT

TOKYO, JAPAN
UNIT 45002
APO AP 96337-0007
DSN: (315)229-3212
Comm: 81-3-5410-4409

AOARD Trip Report

TITANIUM ALLOYS AND TITANIUM ALUMINIDES FOR AUTOMOTIVE APPLICATIONS JAPAN, DECEMBER 1 THROUGH 13, 1993

Dr. Daniel Eylon
Professor
Graduate Materials Engineering
University of Dayton
300 College Park
Dayton, OH 45469-0240
(513) 229-2679

ABSTRACT

I will concentrate in this report on information obtained in the area of the use of titanium alloys and titanium aluminides for automotive applications. Most of the information was obtained from a one-day visit to Toyota Central Research and Development Laboratories on December 3rd, Dr. Takoshi Saito of Toyota, and discussions with Professor Richard Wagner of GKSS during the SAMPE 93 Conference (see complete addresses at the end of this report).

TOYOTA CENTRAL RESEARCH AND DEVELOPMENT LABORATORIES - TCRDL

This laboratory is located in Nagakute near the city of Nagoya-Aichi Prefecture. It was established in 1960 as an independent research laboratory, serving the entire Toyota Group companies including the Toyota Motor Corporation. The automotive related work is by far their largest research activity, however, they do a very wide range of research in other areas such as biotechnology. Out of the 13 research divisions, 5 divisions are in the area of Materials:

Structural Materials
Ceramics and Metals
Organic Materials
Materials Research
Materials Analysis

I was hosted by Materials Division No.1 - Structural Materials, which employs 60 engineers and scientists and has the responsibility for the areas of:
Coating Casting Forming Materials Design Material Testing

Most of my contact was with Dr. Saito who is the point man for the titanium area. I was also given information about TiAl casting by Mr. Nishino, and information about Ti PM by Mr. Furuta. I had an extensive discussion with Dr. Danno-the Material Division No. 1 Director and also had lunch with Mr. Takase-TCRDL Director.

GENERAL

Toyota is interested in introducing titanium to general automotive engines for improved: fuel economy, reduced noise and increased performance (in that order of priority). The fuel economy is ranked very high, the improved performance is ranked very low. They develop materials and processes aimed primarily at two products: valves and connecting rods. The general guidelines that the researchers get from Toyota Motor Corporation is that the car maker is willing to pay only one dollar in added engine cost for savings of 1% in fuel economy. The replacement of all 16 valves with titanium valves is anticipated to result in a 5% improvement in fuel economy. Therefore, the allowed increased cost **for all 16 valves is only 5 dollars or** 30 cent/valve. All their research and development work is aimed at producing very low cost approaches for titanium components. This group works in competition with another group that develops a new generation of heat resistant iron base alloys as a replacement to the 21-4N.

VALVES

The current 21-4N exhaust valves work at 700°C maximum temperature in the lean bum engines. Their new rich burn engine requires 800°C maximum temperature. They develop TiAl valves using PM and casting approach. **The IM approach is not considered at all as an option** because of the projected very high cost of product-4 times the current valve cost. While in the USA PM is not considered as a viable option, it is my impression that they concentrate on PM approach more seriously than on casting. Toyota has an extensive ferrous PM manufacturing capability and using the PM route is very simple for them.

Cast TiAl Valves - They concentrate on the following areas:
- Low cost melting
- Low cost alloys
- Finer grain size alloys
- Permanent mold casting

Low cost coatings

The low cost melting concentrates on induction melting in CaO Crucibles which is cheaper than skull melting. All their test results are from CaO Crucible induction melted material. The alloy is a simple binary 48% Al + Boron or Carbon or Nitrogen minor additions. They melt sponge fines + pure Al. The oxygen level is 1200 ppm (by weight). At the moment they pour only 1 Kg ingots at the lab. They use either 5 cavity investment mold heated to 900°C or 1 cavity steel mold at RT. However, Toyota Motor Corporation already is using 20 cavity steel mold for trial castings in their production casting facility. Of the 3 minor alloy additions, Boron was found to be the most effective for grain refinement without serious loss of elongation. The level of 0.5 to 0.8 wt% seems to give best results. In their process. HIP is not an option at all. The design tensile load is so low, that centerline porosity is considered to be an acceptable solution. Toyota are now running a couple of cars with Cast + HIP TiAl valves, but in the actual process, HIP couldn't be included for cost reasons.

The valves used now by Toyota have no hard stem tip, and TiN was used as tip coating. They are now working on using titanium oxide as a stem coating as a way to lower the valve cost.

The operating stresses are so low that they are not worried about casting porosity, however, creep deformation at 800°C is a major concern for these valves. **RT EL of 0.5% is sufficient for Toyota.** However, Dr. Saito feels that the casting route is still too expensive. I was also asked a few times by a few Toyota people at the lab if we tried titanium as a material for a permanent mold (??!!).

PM TiAl Valves - They use low heat reaction sintering of Ti + $TiAl_2$ powders at 1535°C. This reaction has only 20 K cal/mol heat-of-reaction and it is relatively slow and controllable. The result is almost a fully dense material. They have two alloys: TiAl and TiAl+TiB_2. They made PM valves in two configurations: 1) solid valve; 2) hollow valve. The hollow valve is made out of 2 parts: a) PM hollow stem and b) PM head. The hollow stems require less material and are easier to produce because of the way the powder is green pressed. However, it requires diffusion bonding of the heads. This valve can be used with or without sodium cooling. The hollow configuration makes the valves substantially lighter.

Intake Ti-6-4 PM Valves - Toyota developed a composite of Ti-6-4+TiB particles which has higher HCF than IM Ti-64 because of the higher elastic modulus. The strength, hardness and wear resistance are also very high, and as a result they consider this alloy also for conrods. I was shown both solid and hollow powder configurations.

The powder used was Ti sponge fines from the Hunter process (Sodium reduced) which is easy to cold compact. They showed me a relative cost calculation. If the present 21-4N valve cost 1 unit, forged valve will cost 4 times, sponge fine PM valve will cost the same as 214N while HDH powder valve will cost twice as much.

Dr. Saito believes that the PM will be the way to go for both intake and exhaust valves.

PM Valves will be used in the **as-sintered** condition with no HIP or HT. The best results were obtained from Ti-6 4+10% TiB. It has 99.2% density, E=110 GPa and EL=3%. At 20% TiB, the E is 150 GPa.

SAMPE 93 CONFERENCE DEC. 7-9, 1993

J. Fujiwara of Honda R&D Company presented a paper entitled: Microstructure Evolution and Tensile Property of New Gamma Titanium Aluminide Alloy." This paper was centered around the

development of forged gamma valve for special high performance engines. However, most people in this area in Japan do not consider forged gamma as an option for mass produced valves.

GAMMA VALVES AT GKSS

According to Professor Richard Wagner, GKSS has an extensive TiAl activity which is centered only around casting and PM. In their casting activity, they produced small and large turbine blades. A whole spool of LPT for the Tornado engine was already hot spin tested at the end of 1992.

They have an extensive valve program with Mercedes Benz and Tital (a German Casting house), with 50% government funding and 50% industrial funding. No other car maker or valve manufacturer are involved in the program.

The Alloy used is Ti-48Al-2Cr. All valves are HIP'd. Mercedes already road tested investment cast+HIP valves. **Tital produced already permanent mold valves on a 50 cavity mold and currently working on 156 casting mold to study the process scale up economics.** Such mold size, in my opinion, cannot be associated with centrifuged casting technique.

I was invited to visit their institute at the end of April for further discussion on this subject.

CONTACT INFORMATION:

1) Dr. Takashi Saito
Toyota Central Research and Development Laboratory
Nagakute, Aichi, 480-11, JAPAN
Phone: 011-81-561-62-6111
FAX: 011-81-561-63-5743

2) Prof. Richard Wagner, Director
GKSS
Max-plank Strasse
D-21502 Geesthacht
FR GERMANY
Phone: 011-494152-875202
FAX: 011494152-872534